NASA's Center for Integrated Space Microsystems (CISM); Addressing the Micro-Avionics Needs of Future Deep Space Missions

Dr. Leon Alkalai
Center Director
Center for Integrated Space Microsystems (CISM)
Jet Propulsion Laboratory
California Institute of Technology

As a direct result of a series of briefings to the NASA Administrator, Mr. Dan Goldin, NASA initiated the Deep Space Systems Development Program to develop a series of advanced spacecraft flight-systems for future deep-space exploration. This progam supports NASA's vision and Grand Challenges such as: searching for extra-terrestrial signs of life; establishing robotic planetary outposts and colonies; and inter-stellar exploration. In support of this program, JPL has established a new Center of Excellence called Center for Integrated Space Microsytsems (CISM) which will provide the necessary technology development focus on highly miniaturized, highly capable, autonomous, and reliable micro-avionics systems. As the Center Director for CISM, I will outline the center's research objectives, the target mission technology *pull*, as well as the technology development *push*. CISM has an 'investment portfolio' that addresses both near-term, long-term, and 'far-out' research topics. The near-term focus is on miniaturized avionics architectures for deep-space missions flying in the 2003-2007 time frame. The long-term focus is on the development of *Systems On A Chip* technologies, and the 'far-out' topics include: *Quantum Computing, Quantum Dots, Biological Computing, Biomimetics, Sensors for Bio-Molecular Signatures, Evolvable Hardware*, and other topics. I will also address opportunities for collaboration with CISM for both universities, industry, as well as other national laboratories.

Center for Integrated Space Microsystems (CISM)

A JPL Center of Excellence

Leon Alkalai
Center Lead

JPL

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CISM:

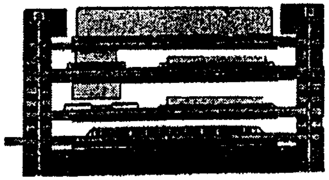
- Is a JPL Center of Excellence (COE)
  (JPL is a NASA COE in Deep-Space Exploration)

- Is an element of NASA's Deep Space Systems Development Program (X2000)

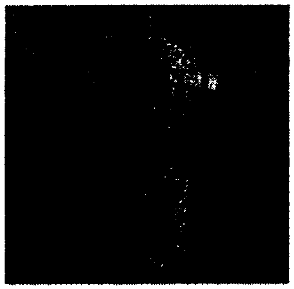
- Main focus is the advanced technology development of integrated avionics systems, system on a chip technologies, and revolutionary computing technologies.

Long-Term Focus on Future Deep-Space Exploration

- Advanced Integrated Microelectronics



- Avionics Systems On A Chip



- Revolutionary Computing Technologies

Enabling Revolutionary Space Science

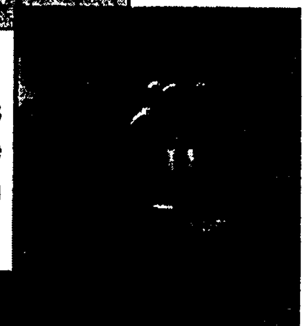
Center for Integrated Space Microsystems (CISM) JPL

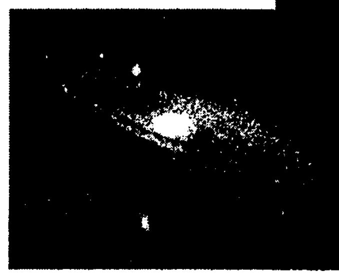
CISM will develop cross-cutting microelectronics and micro-avionics technologies and systems

NMP/DS4
Champollion

Outer
Solar
System

Mars
Sample
Return



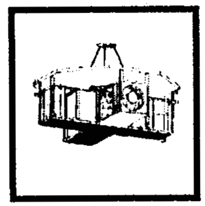


Interstellar
Probe

...and other future missions

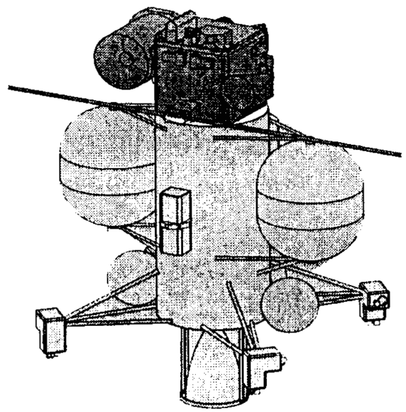
Vision:
Towards a '*Thinking Evolvable*' Spacecraft

"Thinking S/C"

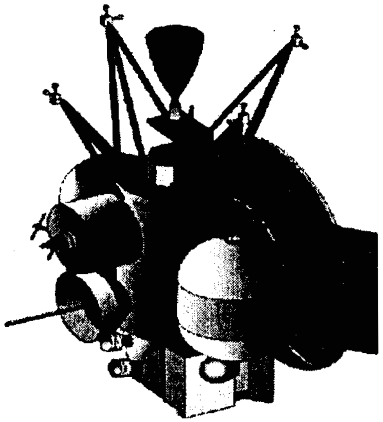


Evolvable HW
Upgradable SW
Autonomous Navigation,
Intelligent Systems

"X2000"

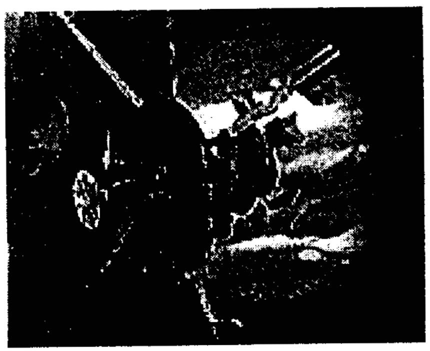


Reconfigurable HW
Upgradable SW



Fixed HW Design
Upgradable SW

"Galileo"



Fixed HW Design
Fixed SW Design

80's State of Art 2006 2020

CISM Goals and Objectives

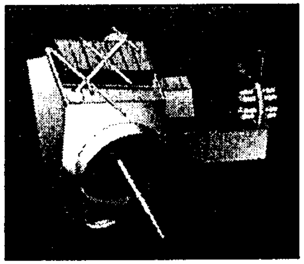
- Develop and maintain a world class, leading edge capability in Advanced Avionic Systems and Advanced Microelectronics Technologies for future highly integrated, miniaturized, autonomous spacecraft for deep-space and Earth orbiting missions.

- Establish and maintain a world class, leading edge facility for the design, development, rapid prototyping, and integration of highly capable autonomous microsystems that include all spacecraft electronics and photonics.

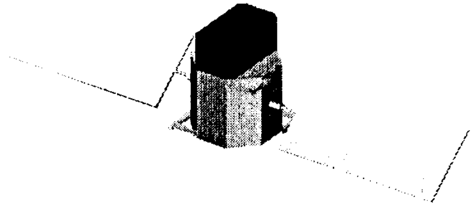
- Establish and maintain world class program to research revolutionary computing architectures that will take us beyond the limits of semiconductor technology scaling e.g. quantum computing, quantum dots, biological computing, holographic storage, optical communications, etc.

Presented to Dan Goldin 7/23/97

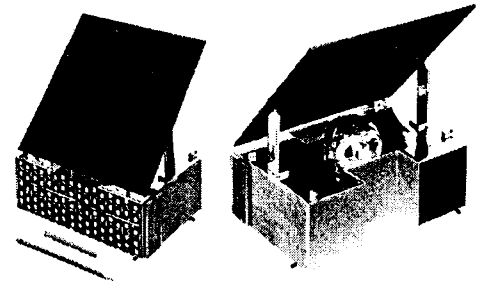
X2000 Strategy: Deliver New Generation of Spacecraft Systems every 3 years



X2000 1st Delivery
(YR 2000)

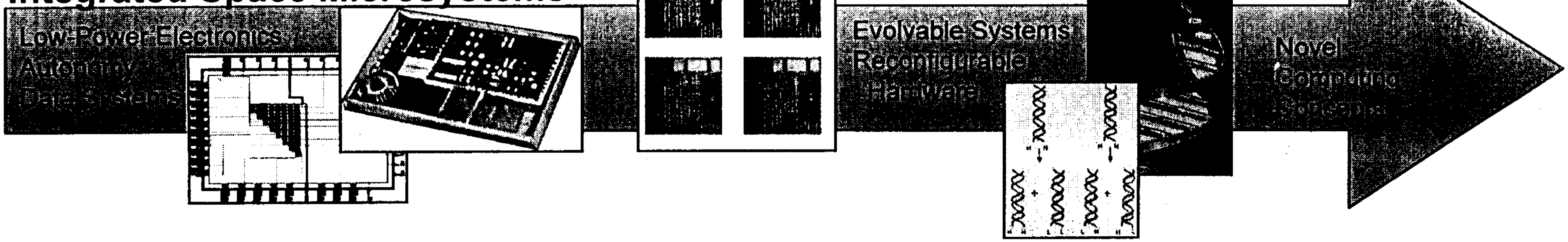


X2000 2nd Delivery
(YR 2003)

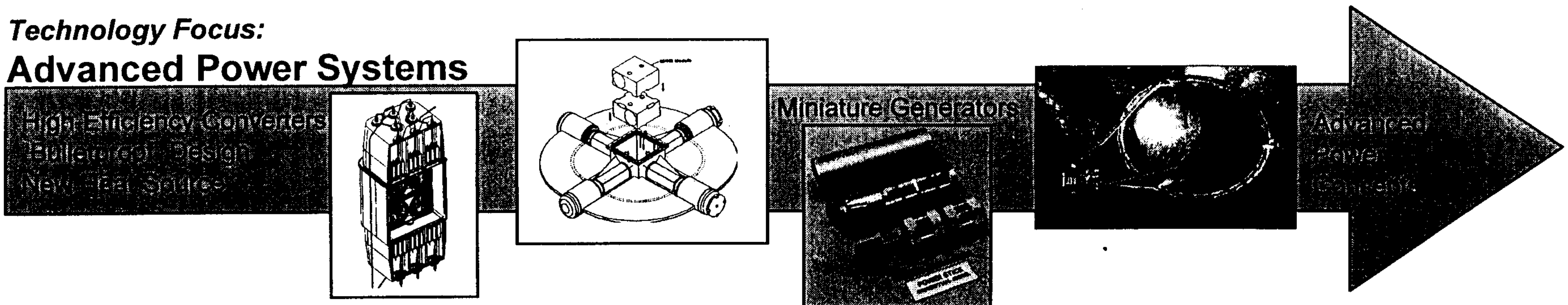


X2000 3rd Delivery
(YR 2006)

Technology Focus:
Integrated Space Microsystems



Technology Focus:
Advanced Power Systems



CISM Organizational Chart

Center Lead
Leon Alkalai

Deputy Center Lead
TBD

CISM Support Staff:
- Heidi Luu, Administrator
- Rani Kamarga, Secretary
- Nancy Livermore, Graphics Support
- Daniel Weisbin, CISM Librarian
- Earl Scott, Facility Management
- Yee Lee, Facility Network Admin.

Programmatic Interfaces:
- SESPD/NMP, Charles Minning
- MEP, E. Kolawa
- TMOD, C. Edwards
- TAP, L. Alkalai
- OEMA, S. Kayali & J. Olivas
- ESD, K. Koliwad

Technology Advisory Board:
- Dave Lavery, NASA HQ
- San Venneri, NASA HQ
- Prof. Peter Kogge, CISM DVS
- Members from industry and Academia

Systems on a Chip
Elizabeth Kolawa

Revolutionary Computing Technologies
Benni Toomarian

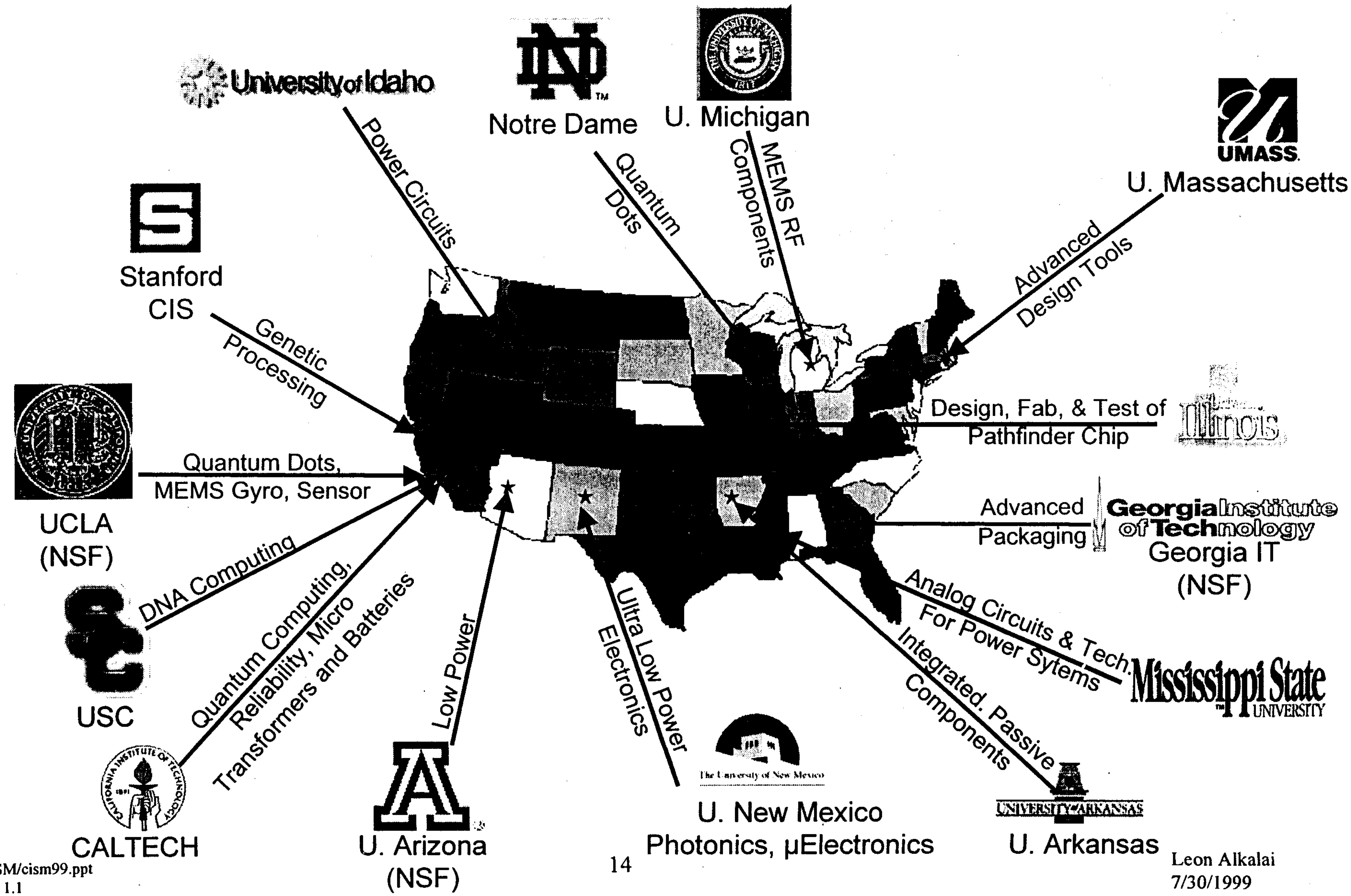
Distributed Reliable Computing
Frank Mathur
Prof. Shuki Bruck, CIT

X2000 1st Delivery
Valerie Thomas

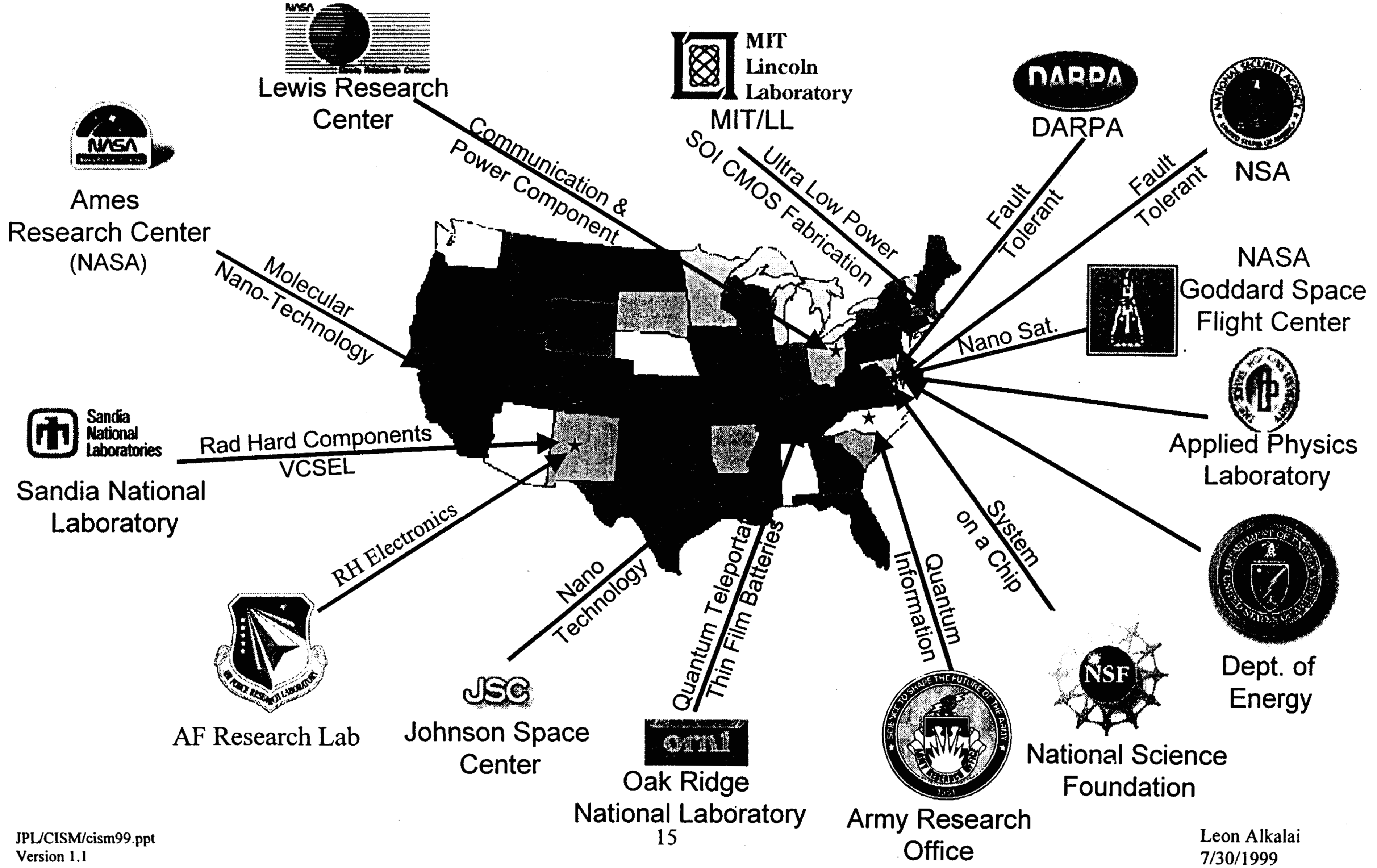
X2000 2nd Delivery
Dan Karmon

X2000 3rd Delivery
TBD

CISM University Collaboration



CISM Government Collaboration



X2000 First Avionics Delivery

X2000 1st Delivery Avionics Challenge

Spacecraft Navigation and Control

Payload Science Interface

* modular, integrated architecture
* integrated telecom, power manage., processing, storage, I/O, and sensors.
* formal specification and simulation
* scaleable, fault-tolerant architecture
* low power design
* commercial, standard interfaces.
* systems engineering and architecture

Holographic Storage

Optical Backplane Com.

High Speed DSP

MEMS/Optoelectronics

Optical/RF Telecom

Power Source

mission enabling | mission enhancing

<u>Goal</u>: 10-20 x reduction in Mass, Volume, Power

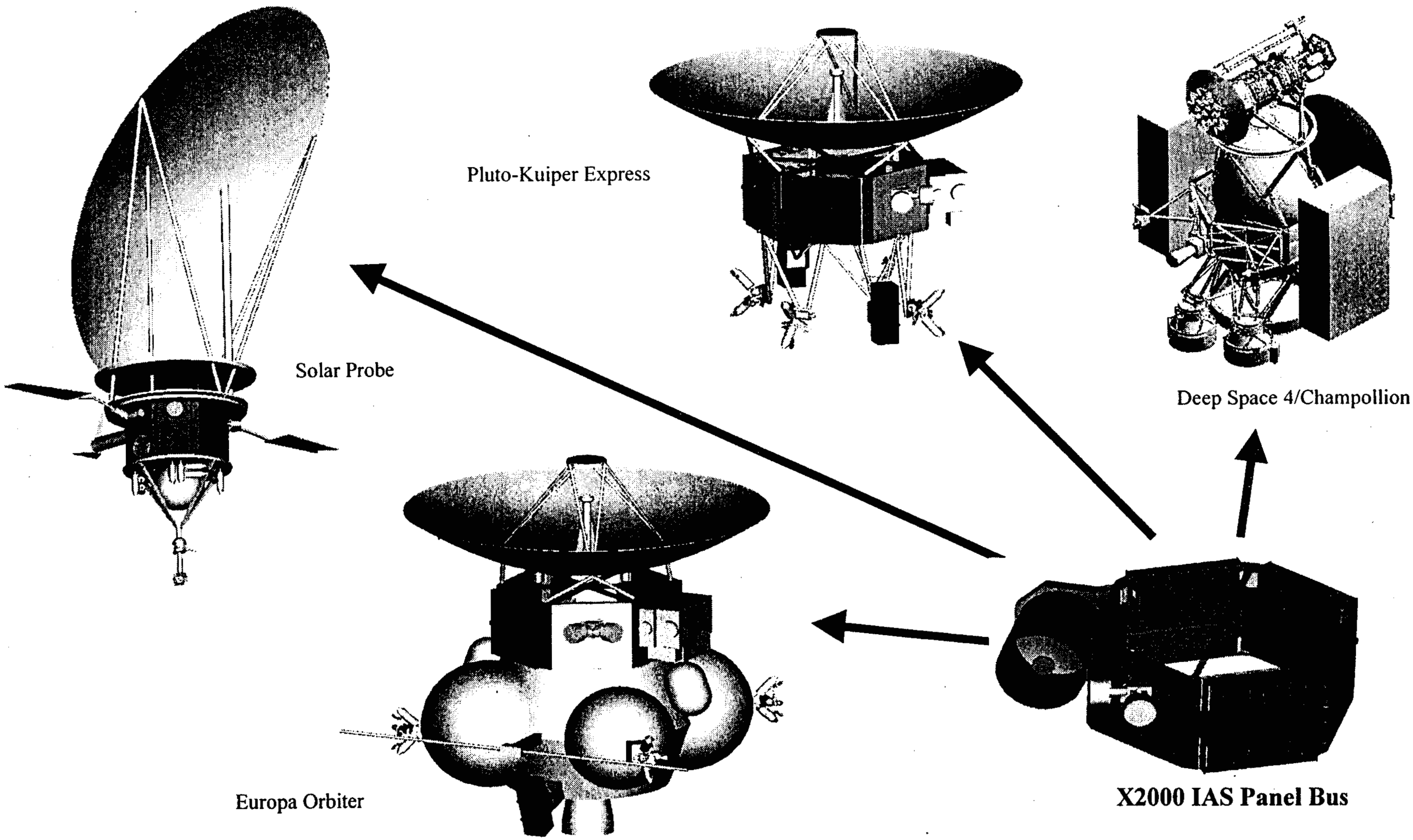
10-20 x improvement in capability

100-400 x growth in functional density relative to MPF

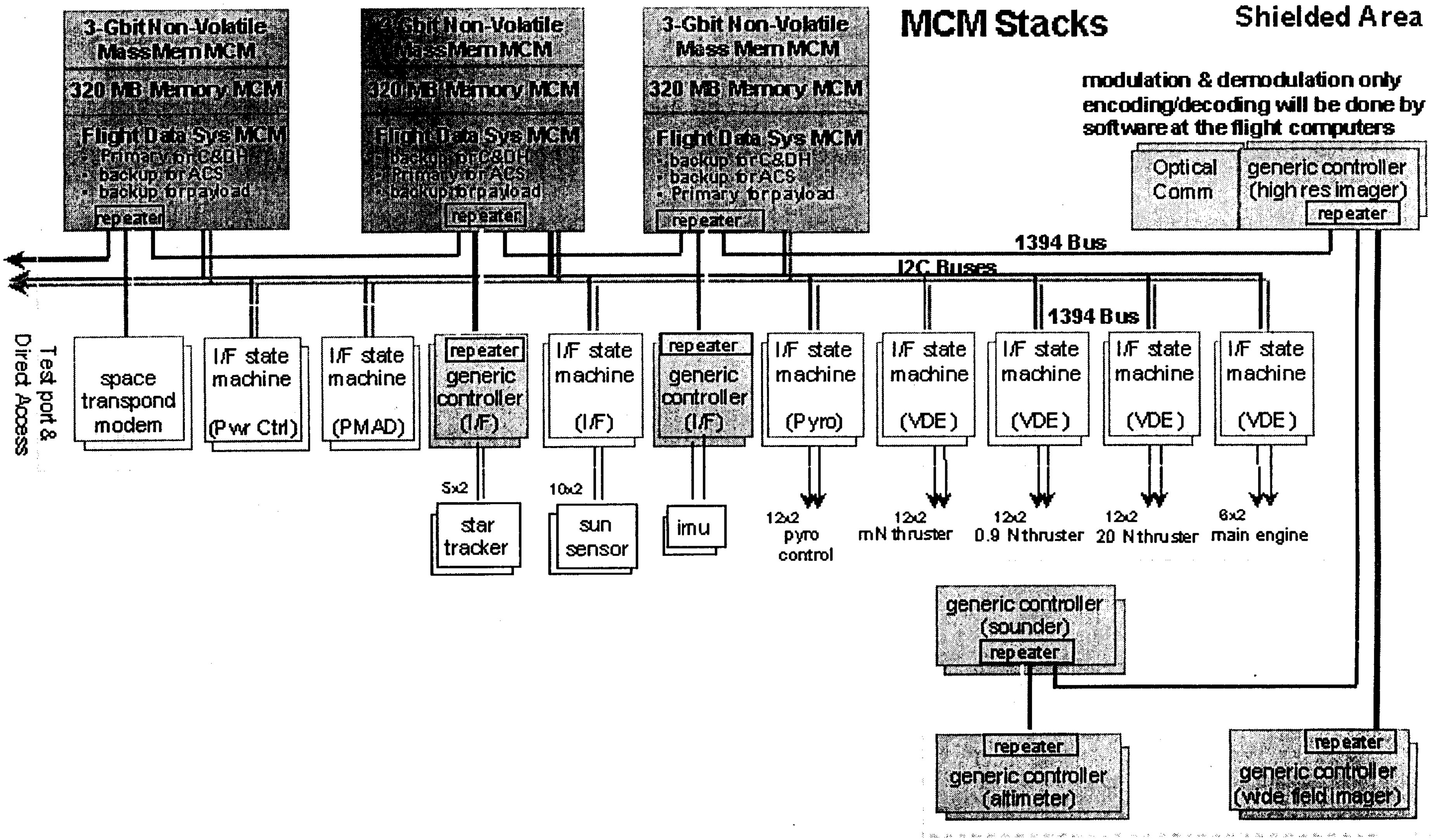
X2000 1st Delivery Integrated Avionics Challenge

- Integrate ALL spacecraft electronics and opto-electronics: telecom, power management, data processing, storage, and sensors, into a single modular design.
- Develop an integrated 3D Microelectronics Systems industry standard.
- HW/SW Design for long-term survivability and fault tolerance.
- Develop Fault Tolerant Distributed Software architectures and techniques.
- Physics of Failure analysis and advanced Reliability Modeling.
- Design for low power architectures including reduced voltage levels, low activation rates, micro-power management, advanced microelectronics packaging, etc.
- Embedded intelligent sensors technology for radiation, temperature, current, voltage, stress, etc. sensing within the microelectronics system.
- High-Level Specification, Design, Simulation, Verification and Synthesis, using formal methods.
- Advanced Systems Engineering using design automation and integration tools; verify design before committing to hardware or software.
- Design for technology scaling: towards a system on a chip.

X2000/CISM 1st Delivery Modular, Multi-Purpose Avionics



Distributed Reliable Avionics Architecture



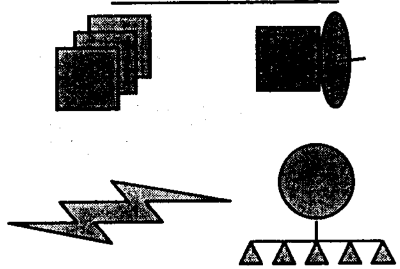
1st Delivery Avionics Technologies

1. Open Architecture for advanced microspacecraft systems based on commercial I/F.
2. New low-cost approach to avionics system development using commercial IP.
3. Common ground/flight hardware/software architecture.
4. Initiating first step towards System on a Chip for 2nd delivery and beyond.
5. Advanced Design Synthesis environment: "Language to layout."
6. Advanced SOAC Digital ASIC technology (SOI, HX3000, 1 M gates, 0.35µ).
7. Advanced mixed signal ASIC technology (SOI, HX2000, 0.8 µ).
8. Distributed Reliable Computing (DRC) Fault-tolerant Architecture.
9. Fault Tolerant tree topology using IEEE-1394 (Firewire) bus.
10. SIFT: Software Implemented Fault Tolerance (CISM goal).
11. Next generation microprocessor technology.
12. Advanced microcontrollers for low power intelligent devices.
13. Low voltage, low power system architectures.
14. Advanced power management and control.
15. Advanced high efficiency power converter.
16. Next generation Power Activation and Switching Module (PASM).
17. VCSEL and RCPD opto-electronics.
18. Advanced modular 3D packaging technology.
19. Radiation Hardened components: ADC, FPGA, SRAM, etc.
20. Radiation Hard sensor technology for Steller Reference Unit (SRU).

X2000/CISM 2nd Delivery Avionics

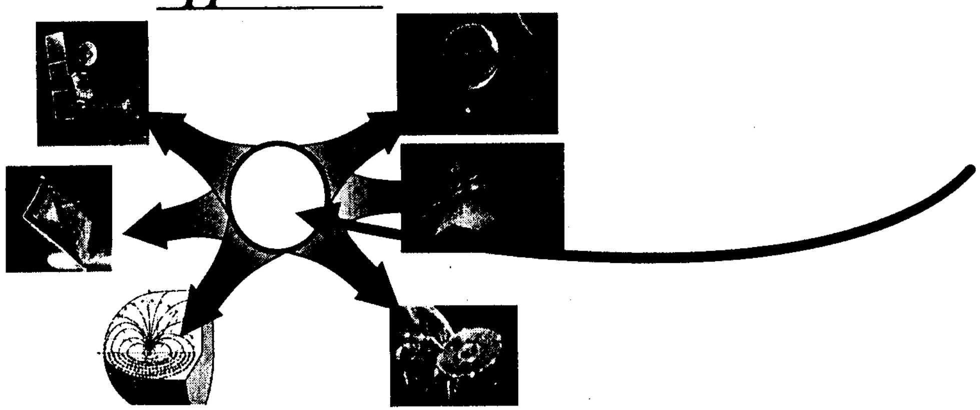
The Approach

Technology

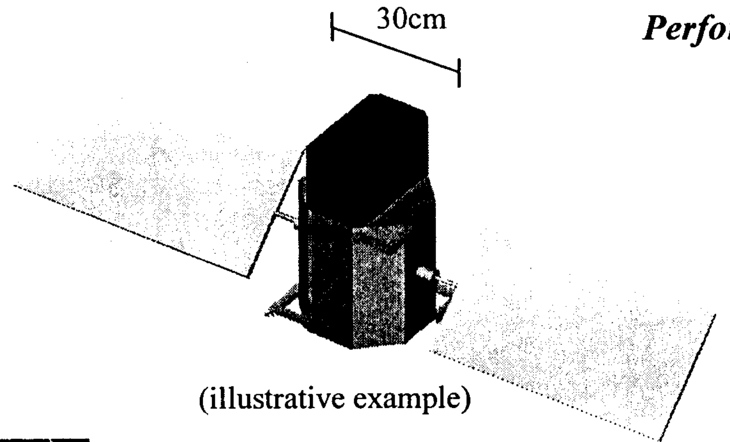


Core technologies
plus others delivered by partners

Application



System Prototype



(illustrative example)

System Mass: **~17kg**

Peak Power Mode: **~20W**

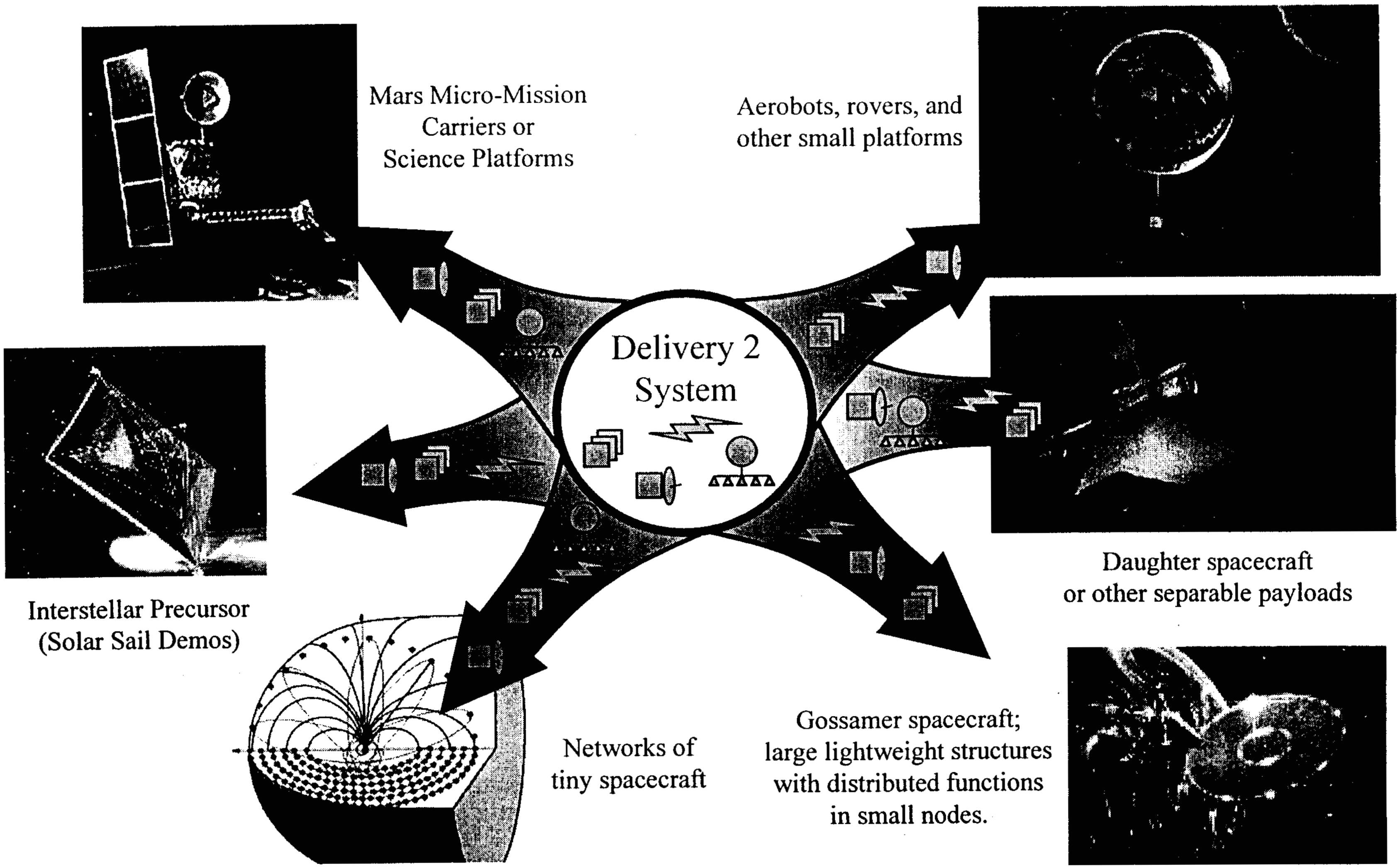
Performance Goals:

- **50m/s delta-V**
- **30 kbps Data Rate @ 2AU (Optical Comm)**
- **200MIPS Processor; ~1GOP Co-processor; 10Gigabit DRAM**
- **Combined Optical Communications/Narrow Angle Imaging Terminal**
- **1 mrad Pointing Control; 0.05 mrad Knowledge**

System Validation:

- **Environmental Testing**
- **Functional Testing**
- **Operational Testing**

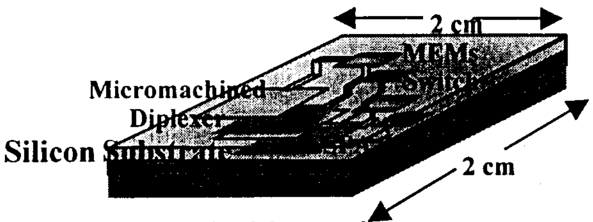
2nd Delivery Will Benefit Many Future Micro-Systems



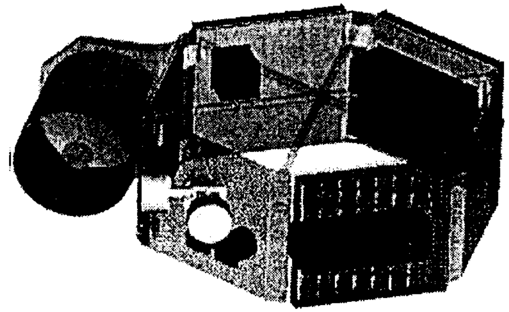
= Integrated Avionics   / = Deep Space/Relay Communications   = Micro Propulsion

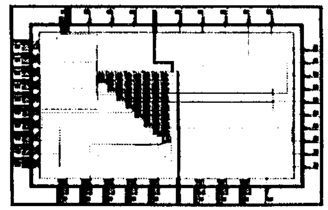
System on a Chip Technologies

X2000 First Delivery: ~10,000cc, ~60 kg, ~150W



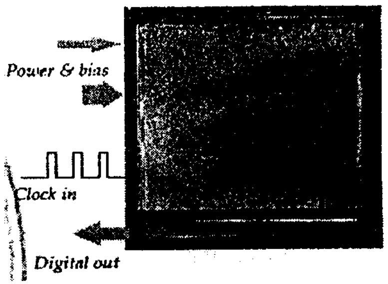
Micromachined front end (diplexers, switches, SSPAs) for miniaturized RF Communication System



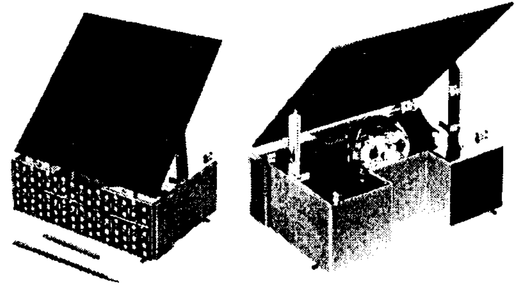


Ultra Low Power architecture and devices

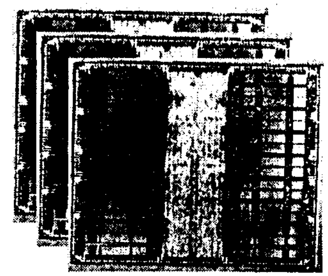
1K x 1K APS



Active Pixel Sensors for low power optical comm. and advanced Star Trackers

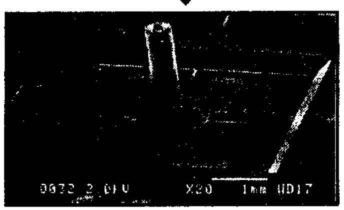


X2000 2nd Delivery <100cc, <10 kg, ~ 30 -50W

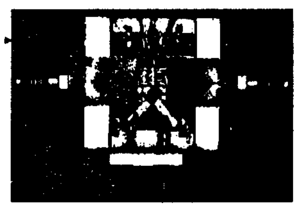


Processor in memory: Multiple CPU per chip with DRAM, SRAM, NVRAM, BIST, Fault Tolerance

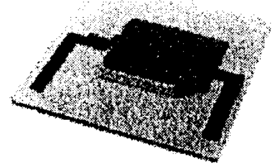
Thin film microtransformers and passive components for miniaturized Power Management and Distribution System



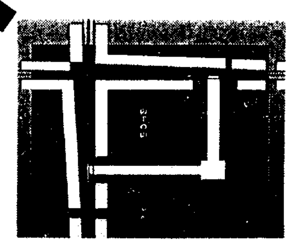
Micromechanical Inertial Reference System for miniaturized Guidance and Navigation System



Thermoelectric thin film coolers for advanced thermal control



Thin film batteries for on chip power storage



High bandwith, low power, optoelectronic switch for high speed optical bus

SOAC-Technology Development Tasks

[illegible] (Program Lead)

Leverage from and collaboration with external sources of funding (NASA, other government agencies, industry)

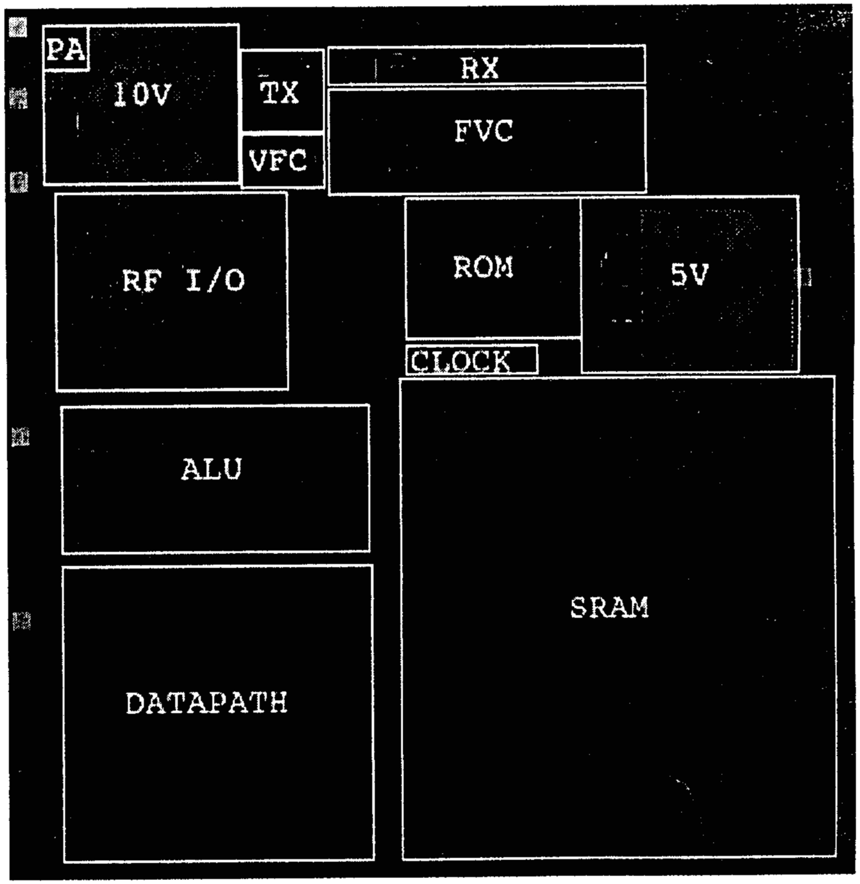
- Hughes, Honeywell, UCLA — [illegible] Inertial Ref. Syst. T. Tang
- U. Arkansas-HiDEC, Oak Ridge Natl. Labs, Caltech — Embedded Passives and Power System Components E. Brandon
- Honeywell, MIT-LL, Allied Signal — [illegible]
- U. Michigan, Hughes, U. Colorado, U. Maryland — [illegible]
- Honeywell, LM, Boeing, MIT-LL — [illegible]
- Caltech, U. Maryland, Stanford, U. N. Carolina — [illegible]
- System Integration, Architecture, Design, Fabrication and Test B. Blaes — Honeywell, Boeing, NSM, LM, MIT-LL, U. Illinois-Chicago, U. Massachussets, UC Davis
- PMAD M. Mojarradi — Honeywell, Boeing, U. Idaho, Missisipi State
- Packaging [illegible] — Sheldahl, Alpine Micr., U. Arkanasas-HiDEC
- [illegible] — U. Illinois-Urbana
- [illegible] — Stanford, Berkeley, UCLA

System on a Chip Prototype
University of Illinois Chip

The UIC system on a chip was selected for multiproject Darpa run at MIT Lincoln Lab as a collaborative effort between U. Illinois-Chicago and SOAC/CISM.

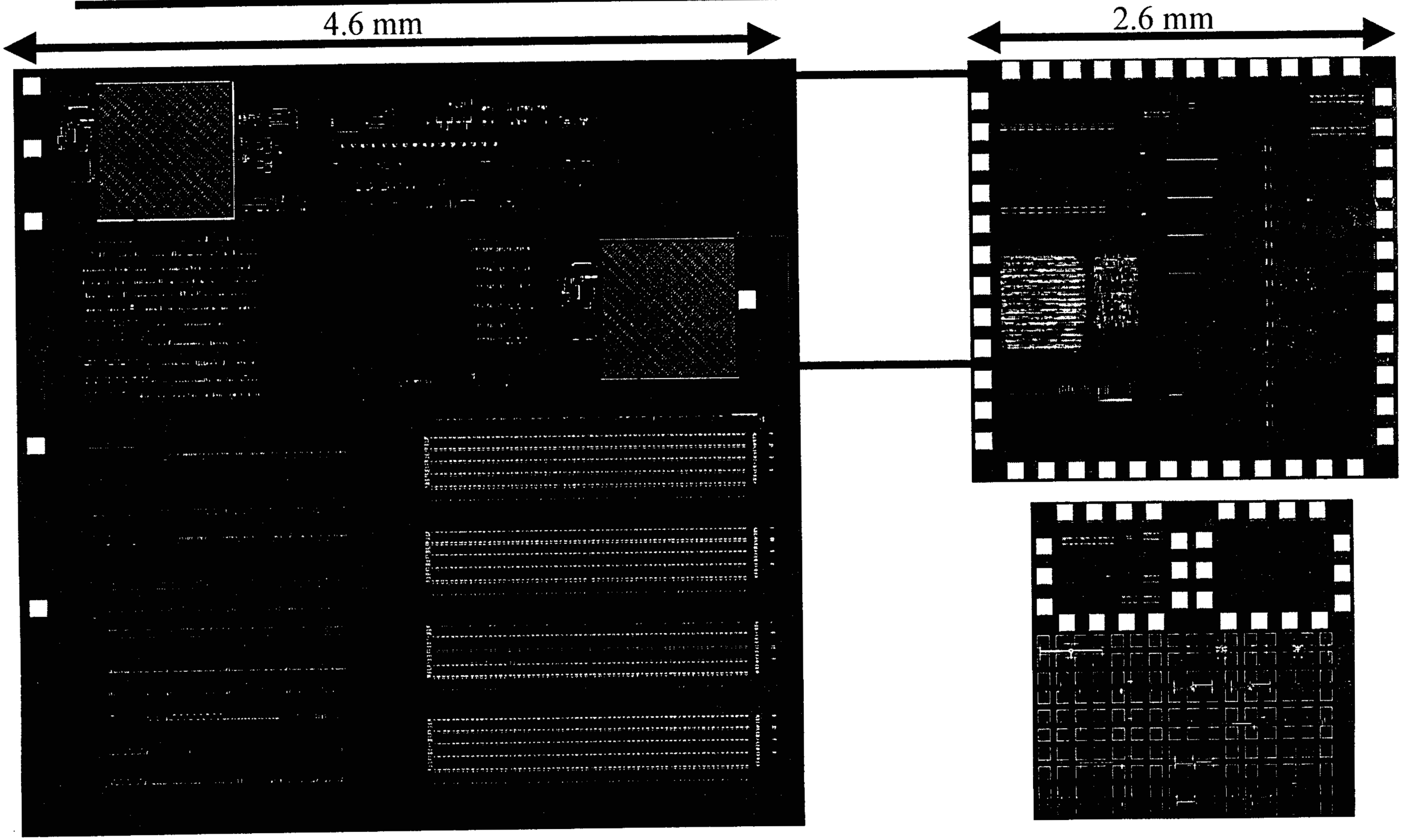
Chip architecture:
- 50 MHz, 8-bit RISC CPU
- 256-kByte SRAM
- RF I/O control
- UHF tranceiver
- on-chip power management and regulation
- on-chip clock generation

Technology:
- already fabricated using MOSIS AMI process: 1.2 um bulk n-well CMOS
- will be fabricated using 0.25 um SOI CMOS in FY'98, 0.18 um in FY'99 in collaboration with LL, Darpa, and industry.



University of Illinois-Chicago UIC chip

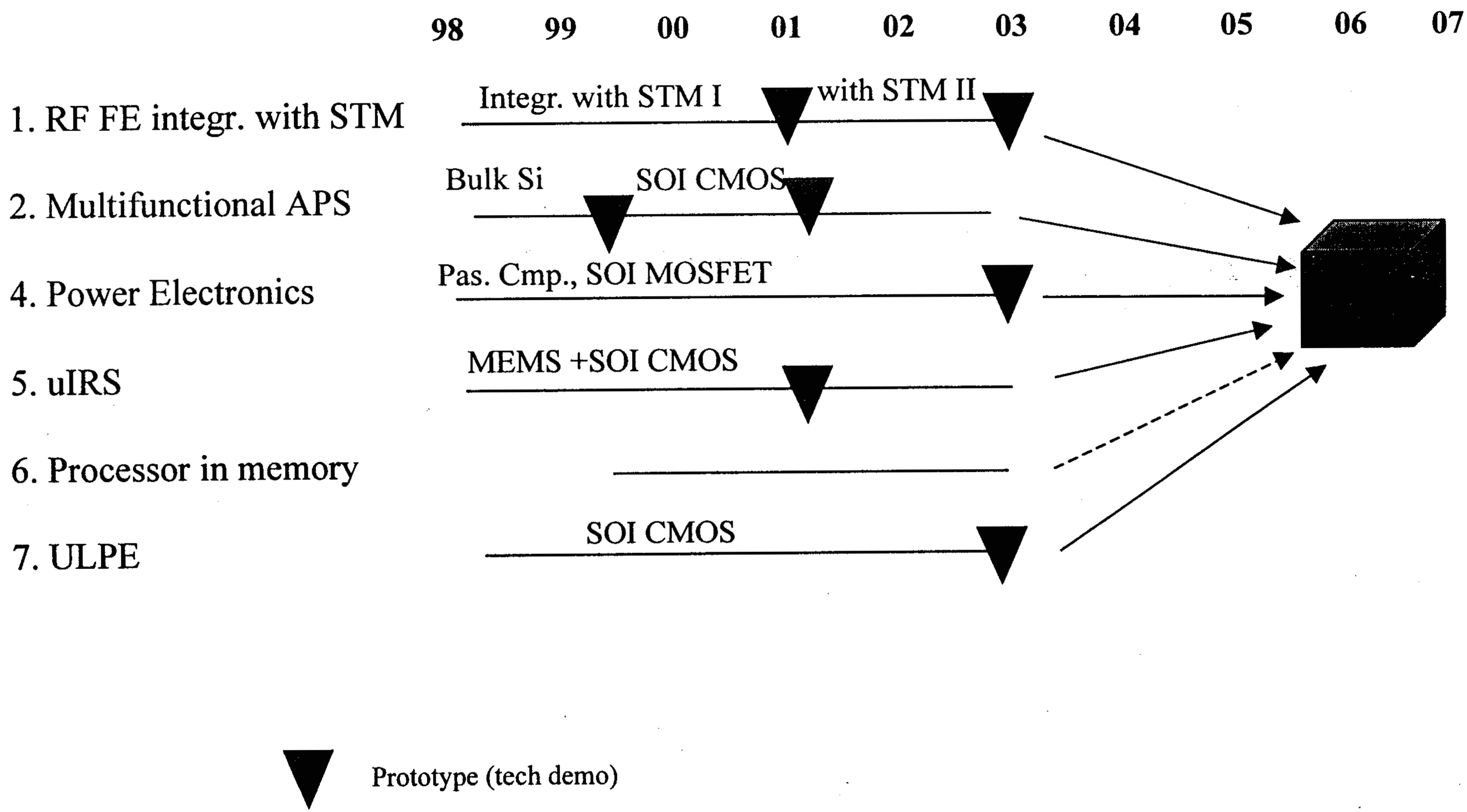
Implementation Comparison



1.2-micron Bulk CMOS

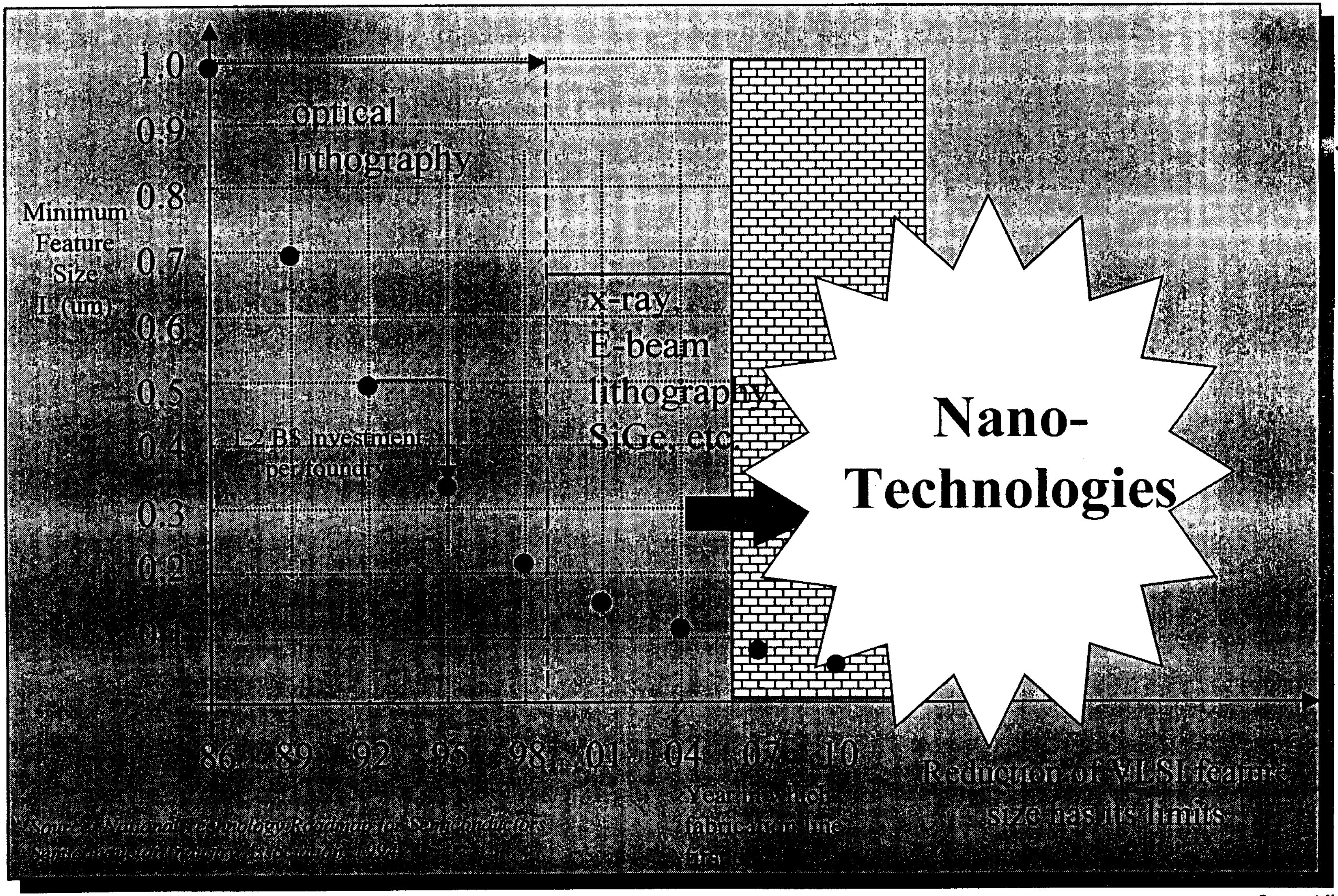
0.25-micron FDSOI CMOS

SOAC - Roadmap



Revolutionary Computing Technologies Program

Revolutionary Computing Technologies
Basic Tech. Challenge



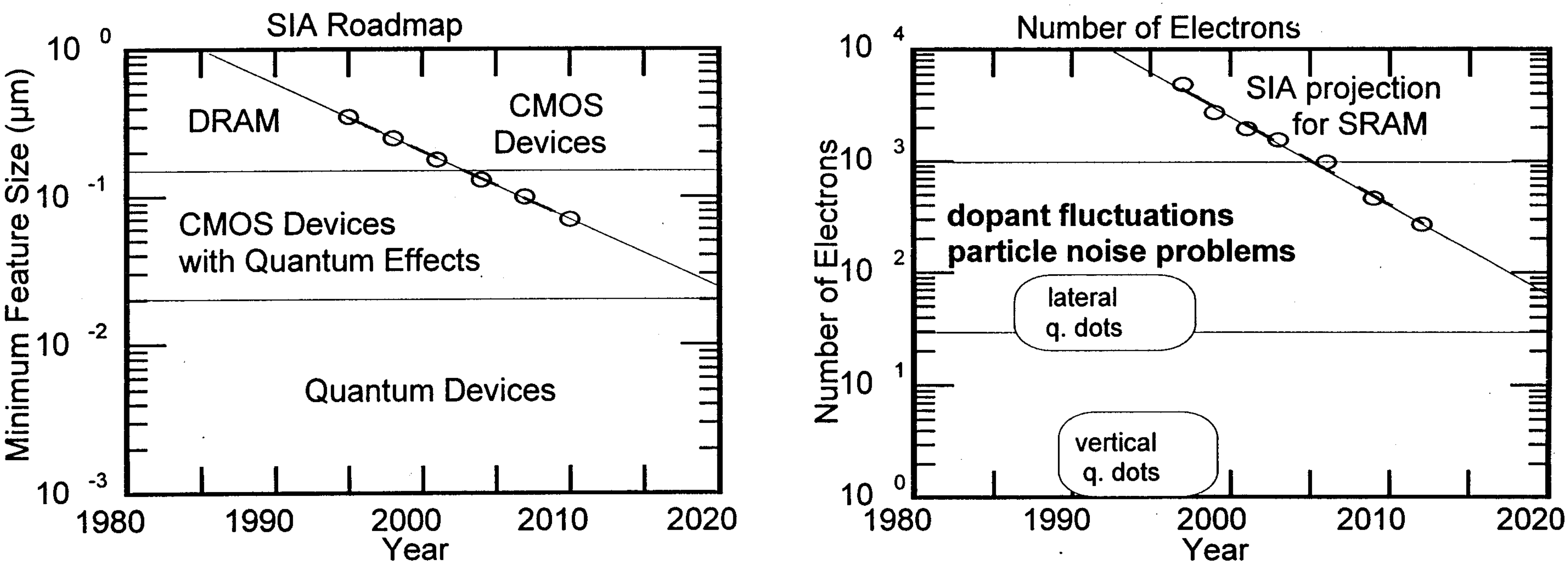
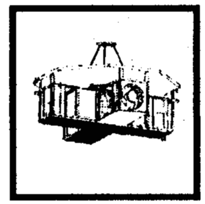


Figure 1 (a) Minimum 2D feature size as projected on the SIA roadmap [1]. (b) Number of electrons under a CMOS SRAM gate [2].

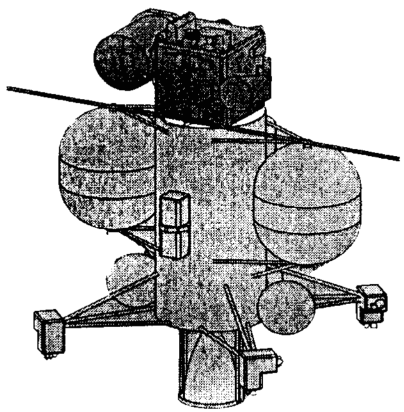
VISION
Toward a Thinking Spacecraft

"Thinking S/C"



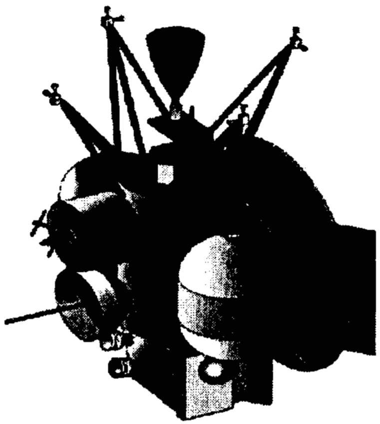
Evolvable HW
Upgradable SW

"X2000"



Reconfigurable HW
Upgradable SW

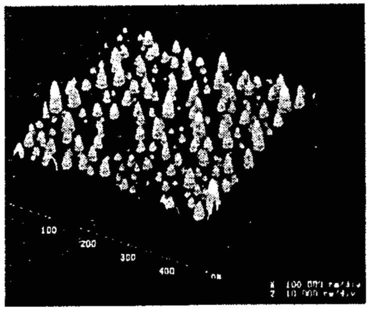
"Sciencecraft '96"



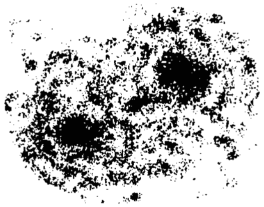
Fixed HW Design
Upgradable SW

- **Hard problem, Multiple technologies**
- **Some of the enabling avionics technologies are addressed**
- **Currently:**
  - **Re-configurable HW**
  - **Evolvable HW**
  - **Opto-electronics**
  - **Biological computing**

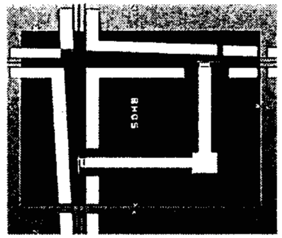
Revolutionary Computing Technologies



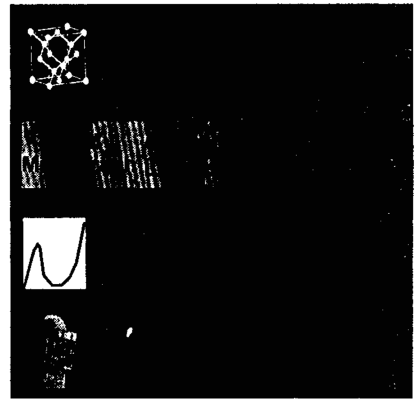
Quantum Dots



Quantum Computing



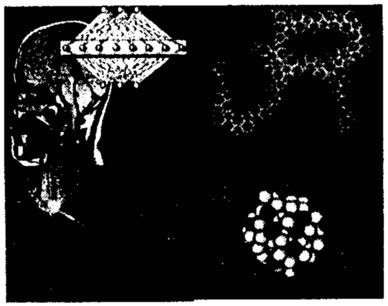
Optical Computing



Nano-technology Modeling

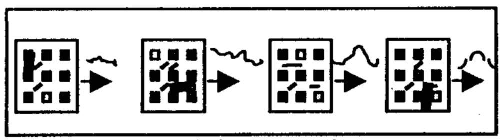
Mission "inspiring"

Breakthrough Revolutionary Computing Technologies & Architectures

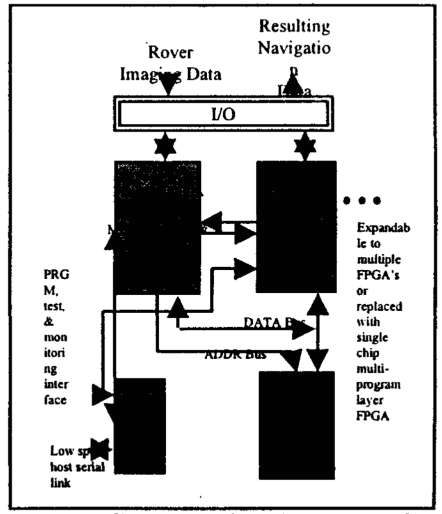


Biological Computing

DNA Computing

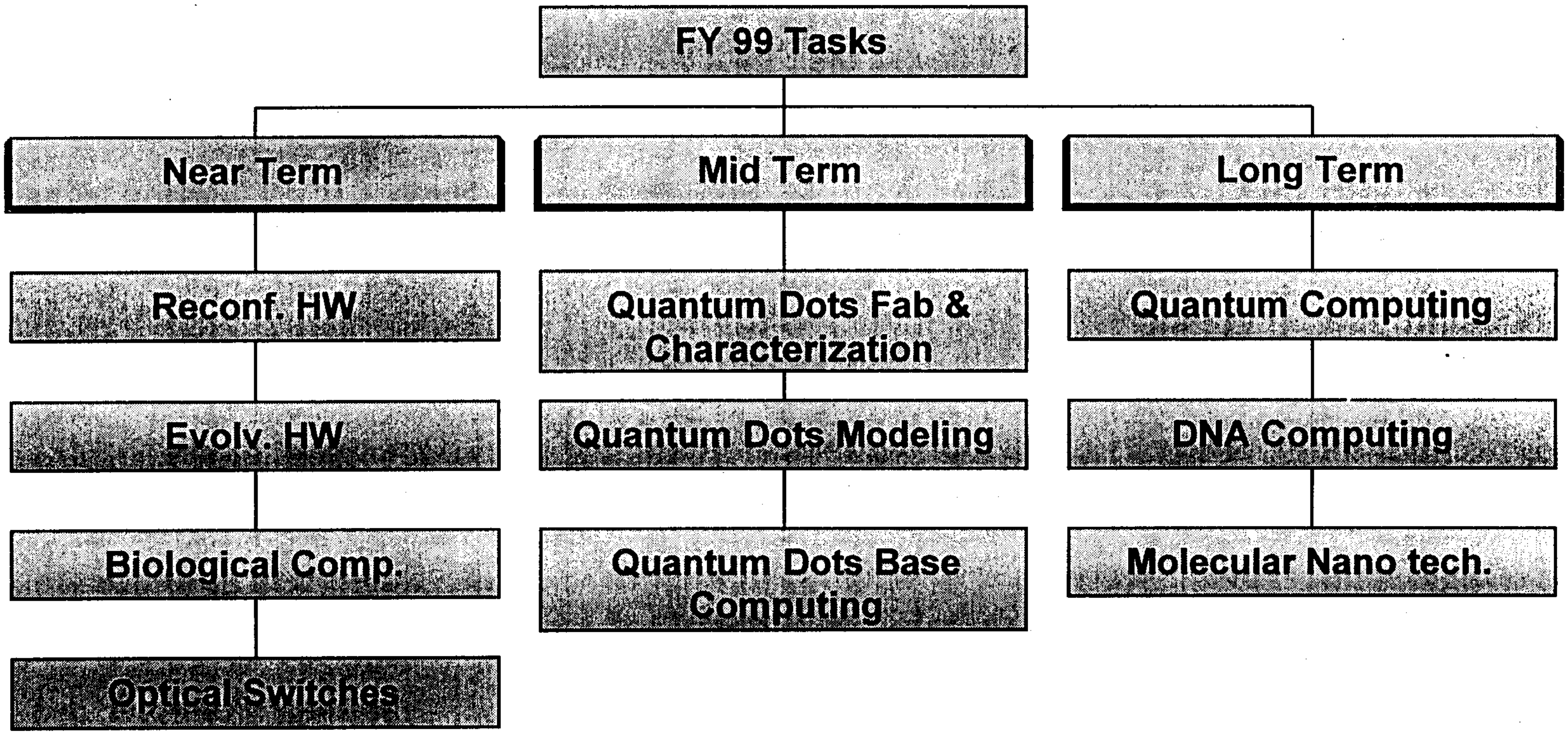


Evolvable Hardware

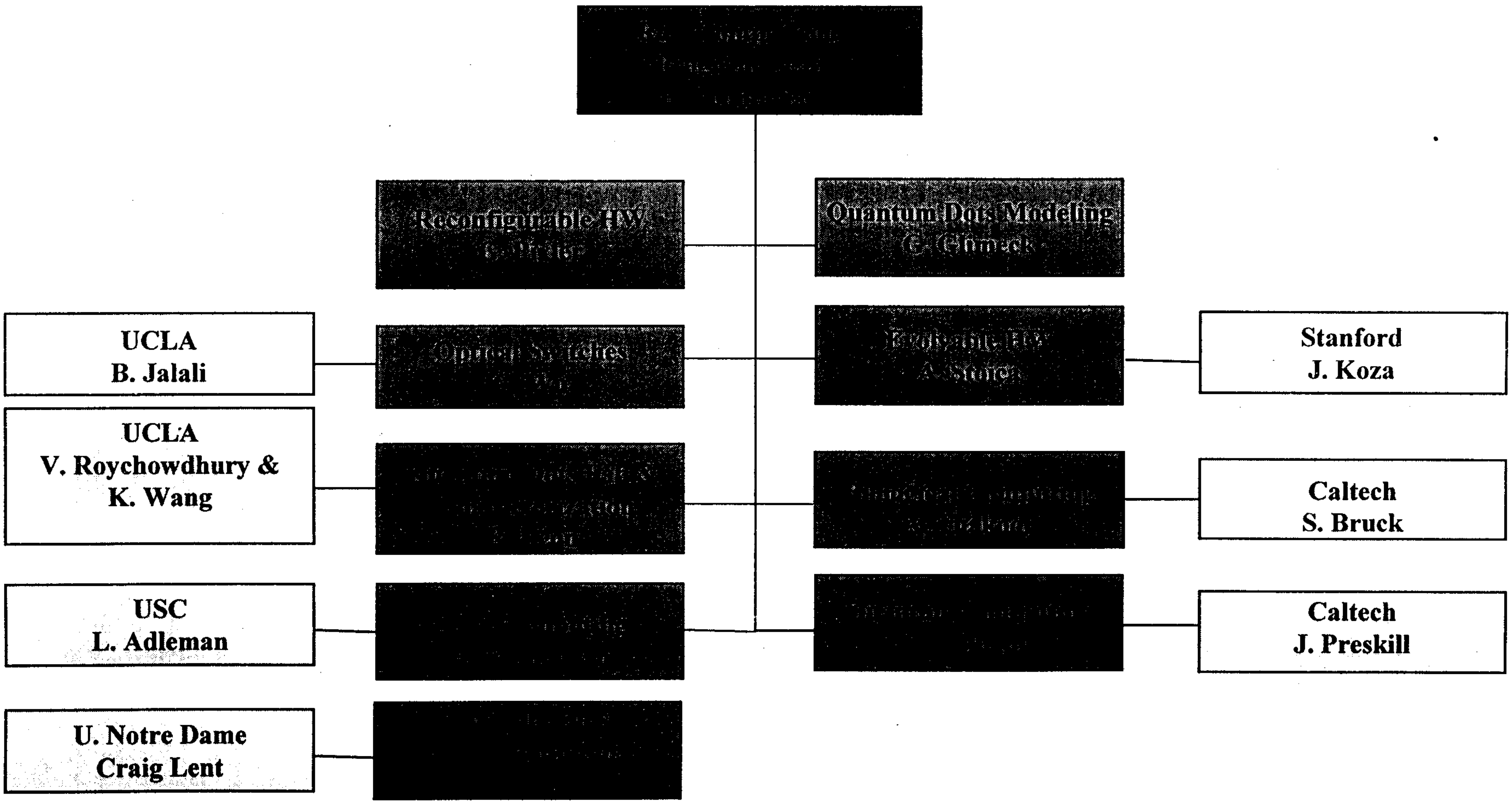


Reconfigurable Computing

FY 99 RCT Portfolio



RCT - University Contracts



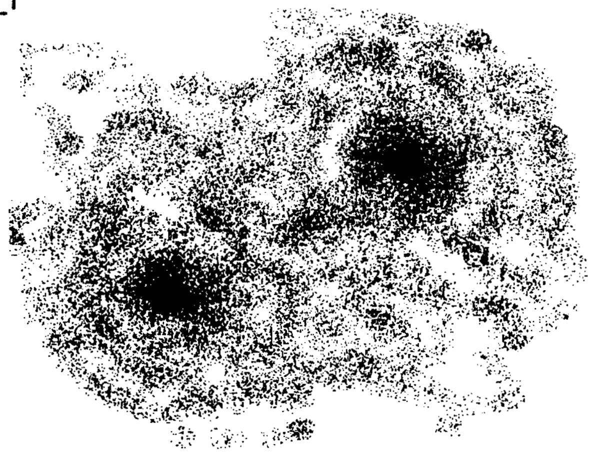
Quantum Computation and Information

QIC builds upon:

- Superposition
- Interference
- Entanglement

Advantages:

- Speed
- Security
- New opportunities



Expertise Needed:

- Computer Science
- Quantum Physics
- Device Physics & Eng.

Challenges:

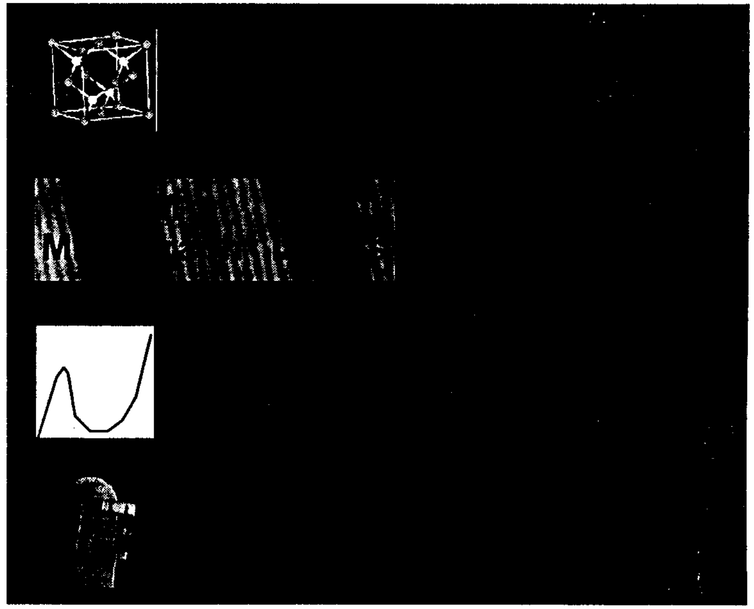
- System Issues
  - Decoherent Problem
  - Measuring Problem
- New Approach to Formulate Problems

NASA Relevance:

- Fast Computing:
  - Spacecraft Applications
  - Grand Challenge Problems
- Fast Communications
- Secure Communications
  - Data Compression

Engineering Tools for Advanced Devices and Concepts

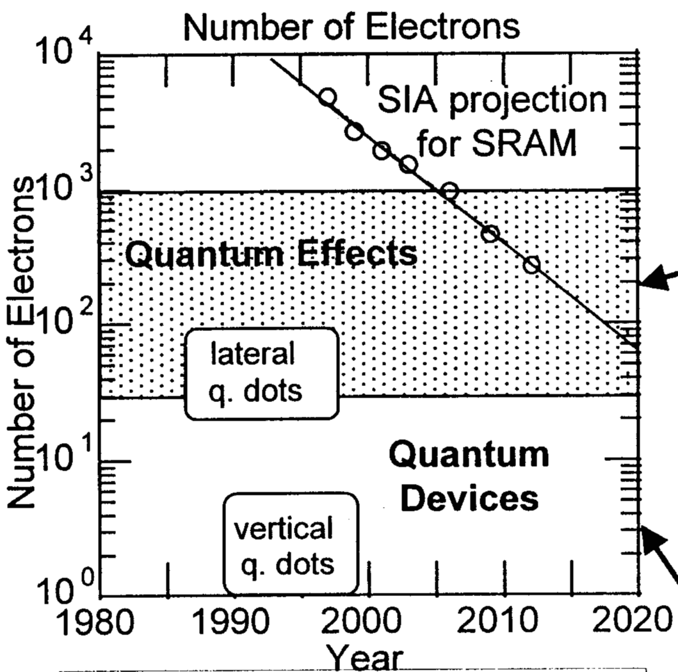
Objective:
- Provide engineering design tools for electronic and photonic dev.
- Near Term:
  - 1-D and 2-D structures: RTDs, QUIPs, HFETs, HBTs, Lasers (far IR, near IR).
- Long Term:
  - 3-D structures: Quantum dots, quantum dot arrays, automata, nanotubes.

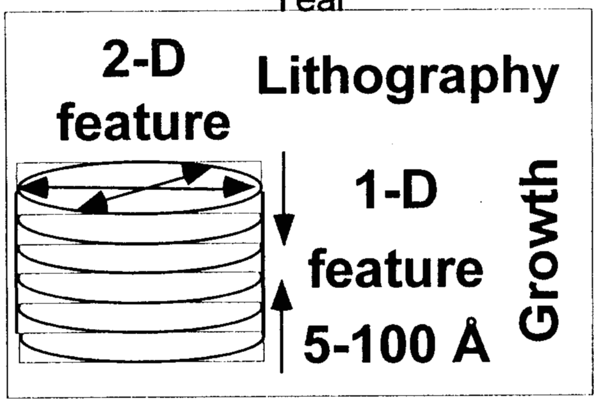


Approach:
- Bring in advanced modeling tools from research institutions (NEMO, MINILASE, ...)
- Build new models if necessary.
- Co-integration of the tools into ONE common WEB-based worksurface.

Impact:
- Enable device optimization for microelectronic-based missions.
- Near Term:
  - Optimize devices.
- Long Term:
  - Provide vision and modeling for new architectures beyond the SIA roadmap.

Nano-technology Modeling





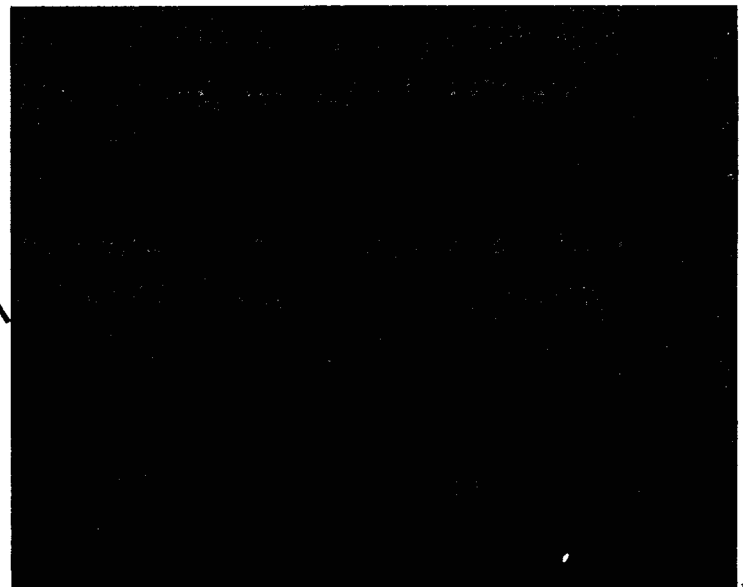
Reduction of Device Size

↓

Reduction of electron #
Reduction of dopant #

↓

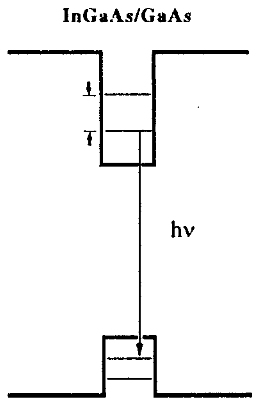
Strong electron and dopant fluctuations

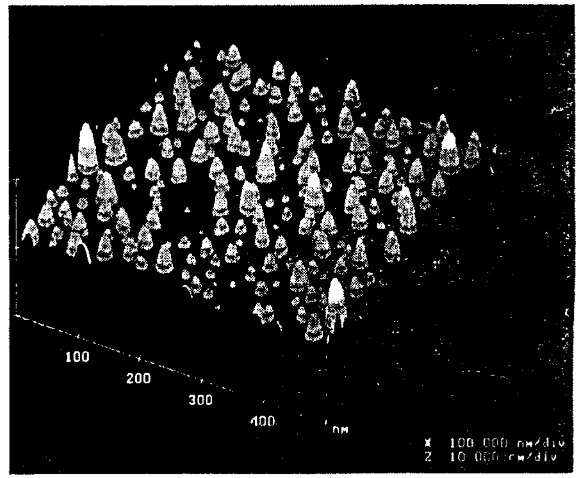


Self-forming Quantum Dots for Space Applications

- **Quantum dots (QDs): structures capable of confining carriers in three dimensions**

- **Advantages of self-forming semiconductor QDs:**
  - Spontaneous strain induced island formation allows defect free interfaces
  - High packing densities (10^{11} dots/cm^2)
  - very small dimensions are achievable
  - Compatible with modern epitaxial semiconductor technology.
  - Better radiation tolerance is expected (compared to quantum wells)



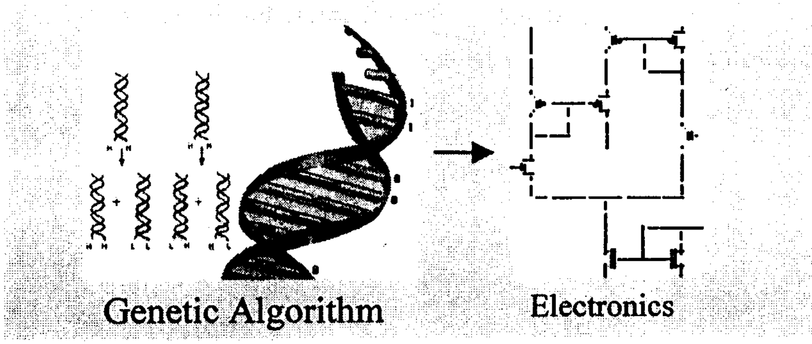


- **Applications:**
  - Sensitive infrared detectors with lower dark current and better temperature robustness
  - 0-D lasers: higher gain and lower threshold currents
  - Transmitters for WDM (photonic circuits)
  - Room temperature Frequency domain Optical Storage Devices
  - Single electron devices - Quantum computing?

InAs/AlGaAs quantum dots cross section TEM micrograph

Evolvable Hardware

Objective: Develop microelectronics chips capable of self-reconfiguration for adaptation to the environment

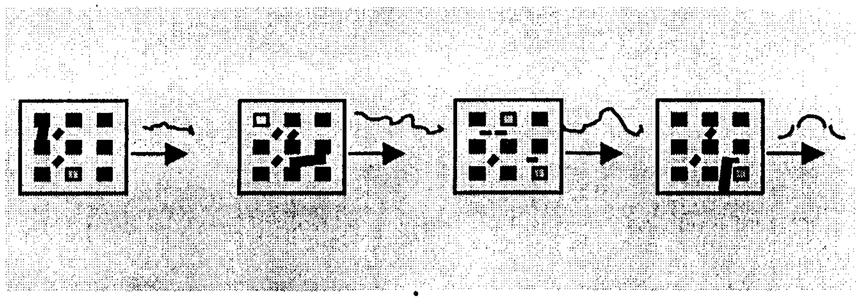


Payoff: **Achieve high autonomy on-board spacecraft**

- **Maintain functionality under changes in operating conditions**
- **Provide new functions, not anticipated on ground**

Approach:

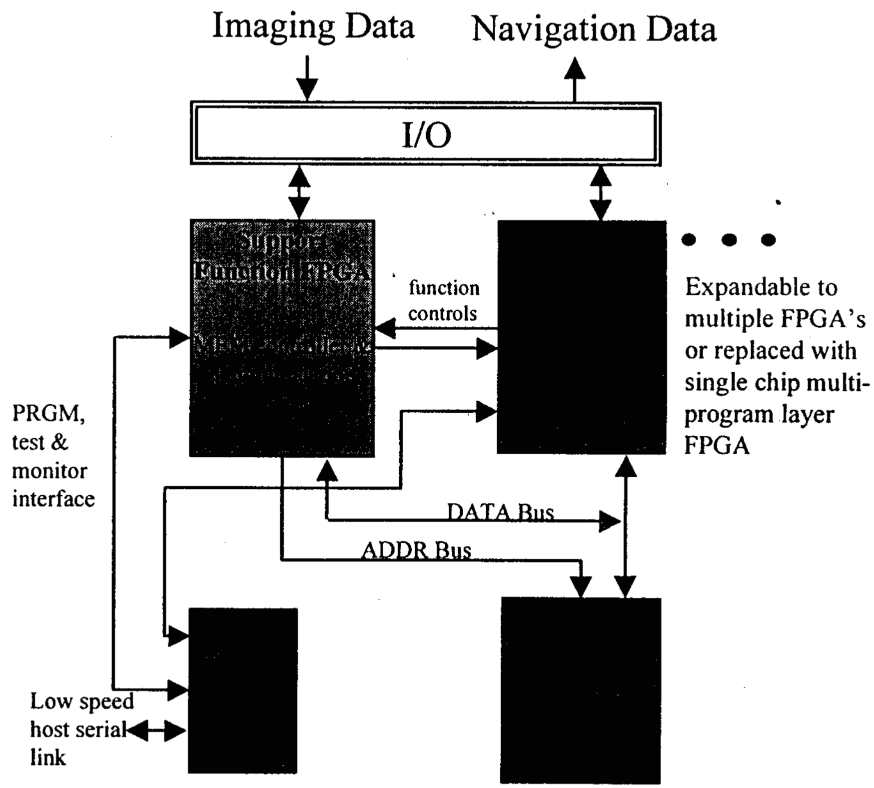
- **Use reconfigurable cells**
- **Achieve self-organization by reassigning cell function & conncetions between cells**
- **Use powerful parallel seraches (e.g. genetic algorithms) directly in hardware, to evolve chip architecture**



Reconfigurable Computing

Objectives:

- Develop a spaceflight-quality reconfigurable computing capability which will allow:
  - Faster, cheaper development cycles
  - In-flight failures to be fixed via reconfiguration, resulting in higher reliability
  - Hardware-based algorithms to be reconfigured in flight in response to changing conditions
  - A common hardware assembly to perform multiple functions



Approach:

- Developing HW & SW environment that will enable use of reconfigurable FPGA
- Demonstrate static reconfigurability on selected X2000 applications
- Demonstrate dynamic reconfigurability on rover navigation based on stereo vision

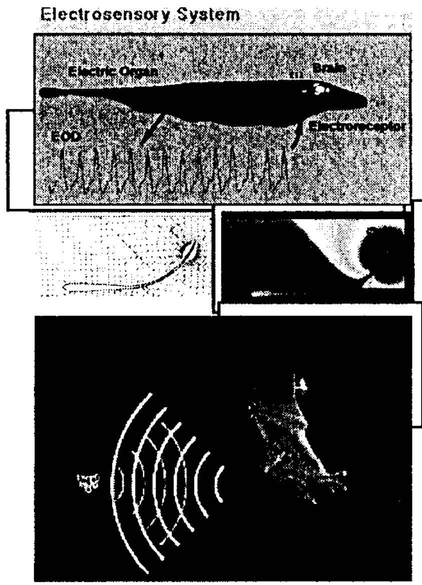
Applications for Future Space Missions:

- X2000, In-situ science, multi-spectral imaging, and many other space science applications.

Biomimetic Computing

Goal

Use information processing techniques derived from biology to enhance and/or add sensing capabilities



Features

Very high sensor sensitivities even with poor individual detectors and in the presence of significant noise

Benefits

Expanding spacecraft science and engineering/navigation sensing options and increasing sensitivities and resource use efficiency

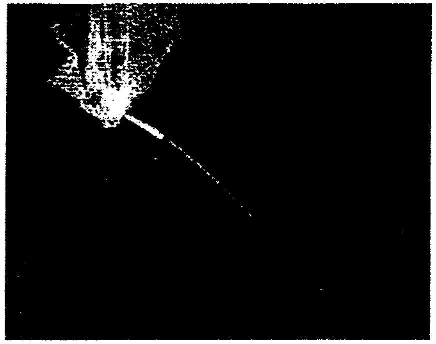
Potential

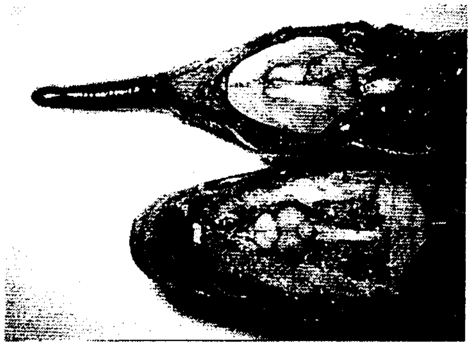
Highly efficient sensing systems approaching theoretical limits of sensitivity

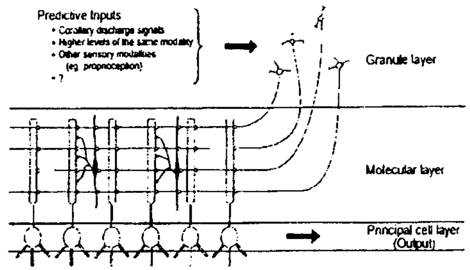
Challenges

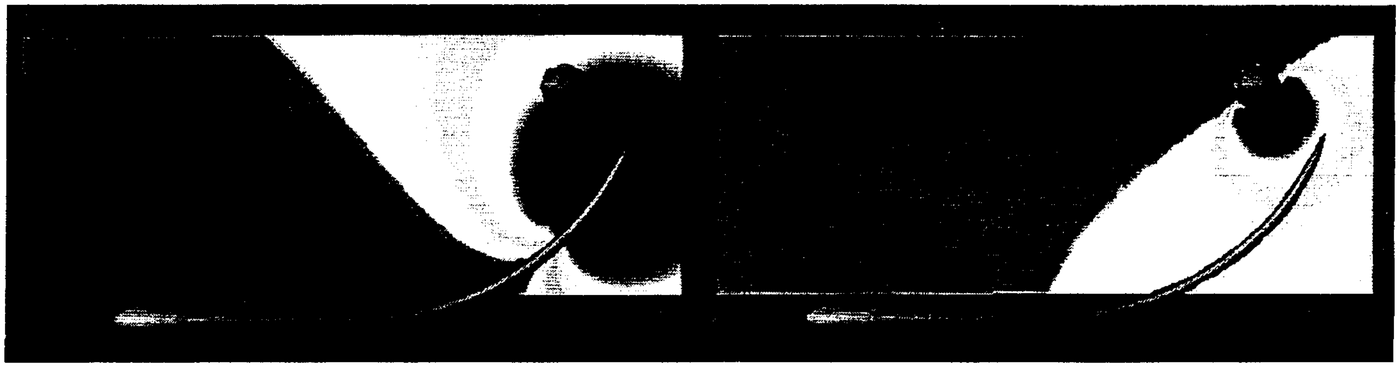
Understanding biological processing techniques and applying the techniques to important applications

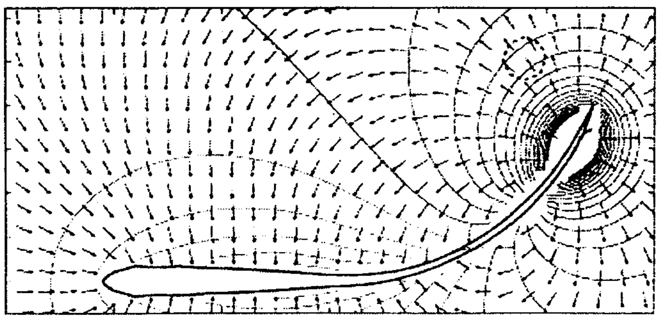
Electrolocation in Electric Fish

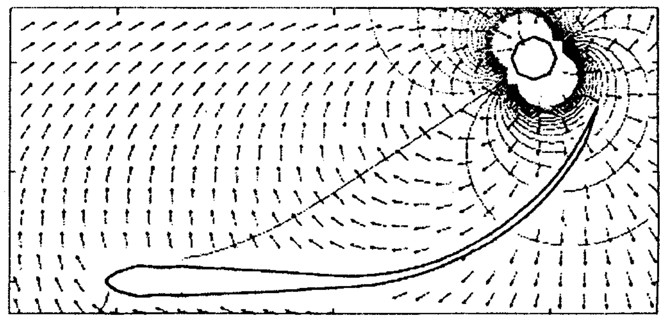








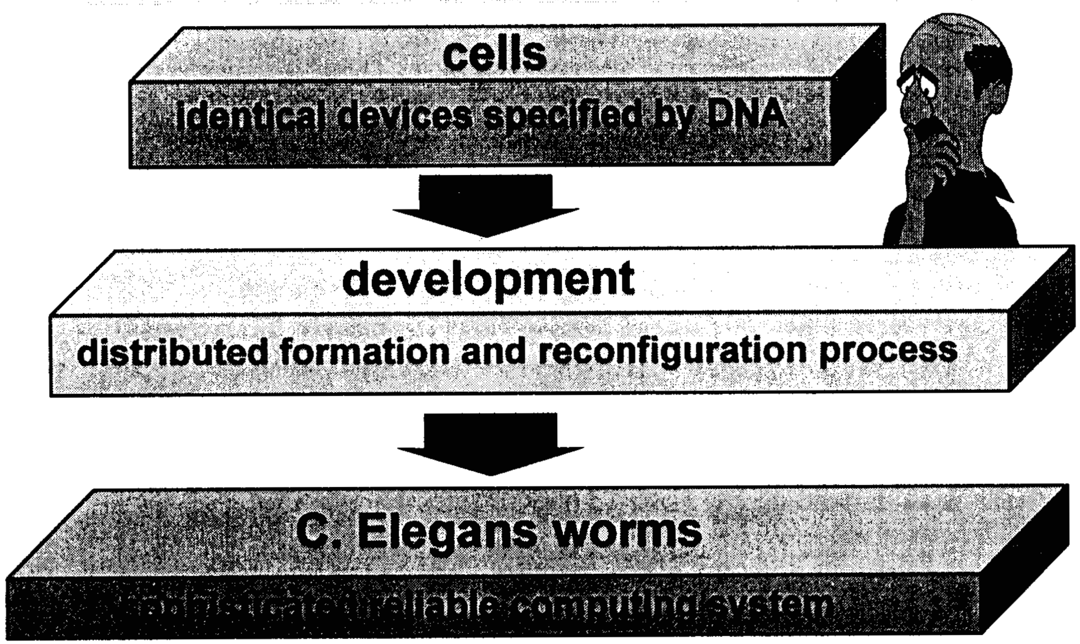


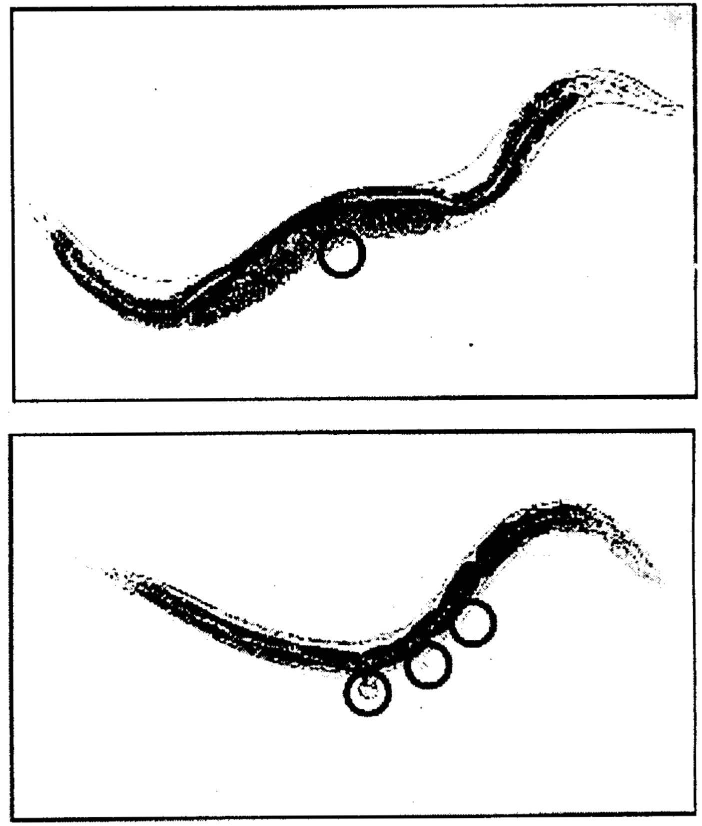


Revolutionary Computing (highlight): Biological Computing Example

highly accurate development process

total of 959 cells, 302 nerve cells, 131 cells destined to die





C. elegans with multiple valvas due to mutation of the ras oncogene.

Dr. R. Horvitz, MIT

Bio-Microexplorers

Enabling better spatial coverage and access to hard to reach and hazardous areas at low recurring cost